Geoindicators Scoping Report for Cape Cod National Seashore

Strategic Planning Goal Ib4

Field Trip: November 3, 2001
Scoping Session: March 11, 2002

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Executive Summary

Staff of Cape Cod National Seashore, the National Park Service's Geologic Resources Division, the U.S. Geological Survey, and the National Oceanic and Atmospheric Administration participated in a field trip that highlighted the geology of Cape Cod National Seashore on November 3, 2001. A follow-up conference call was held on March 11, 2002. The conference call served as a geoindicators scoping meeting, the purpose of which was to bring together park staff, geoscientists, and other resource specialists to address the issue of human impacts on geologic processes at Cape Cod National Seashore. The participants used their institutional knowledge in discussing the geologic processes active in the National Seashore and identifying known human activities that are affecting these processes.

This report is a summary of that discussion and completes the objective of the Government Performance and Results Act (GPRA) Goal Ib4. The report is designed to be a tool for making management decisions in Cape Cod National Seashore, as well as be a representative summary for parks with similar resources, processes, and patterns of use. The report includes recommendations for potential research studies, inventories of geological resources, long-term monitoring of those resources, and incorporating geology into public education efforts.

Geoindicators are measurable, quantifiable tools for assessing rapid changes in earth system processes. Geoindicators evaluate 27 earth system processes and phenomena that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions. The National Park Service uses geoindicators to guide discussions at scoping meetings. The geoindicator scoping process is designed to help park managers anticipate what changes might occur in the future and identify potential management concerns for ecosystem health, operations, planning, and development from a geologic perspective.

Of the 27 geoindicators, 19 were selected as being significant for Cape Cod National Seashore. The participants of the scoping meeting rated these geoindicators (Table 1) with respect to importance to the ecosystem, human impacts, and management significance. The ecological importance of 14 geoindicators (74%) is considered high. Twelve of the geoindicators have been highly impacted by human activities (63%), and management significance is rated high for 12 (63%). Nine geoindicators (47%) are considered high in all three categories:

- Shoreline Position
- Groundwater Quality
- Groundwater Chemistry in the Unsaturated Zone
- Groundwater Level
- Surface Water Quality
- Wetland Extent, Structure, and Hydrology
- Streamflow
- Stream Sediment Storage and Load
- Slope Failure (rated high for human impacts on a local scale)

Scoping Meeting Participants

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1.0 Introduction

The National Park Service (NPS) is gathering information to meet its performance management goals and provide a knowledge base that is needed to address its stewardship responsibilities. To better understand geologic resources in parks, the NPS developed a Servicewide goal to identify geologic processes at work in the parks where human activities are influencing the rates of change and health of natural processes. On November 3, 2001, staff of Cape Cod National Seashore, the NPS Geologic Resources Division, the U.S. Geological Survey, and the National Oceanic and Atmospheric Administration participated in a field trip that highlighted the geology of Cape Cod National Seashore. A follow-up conference call was held on March 11, 2002, which served as a scoping meeting with the purpose of bringing together park staff, geoscientists, and other subject matter specialists to address this goal. This report summarizes the group's findings and satisfies a requirement of the Government Performance Results Act (GPRA) Goal Ib4.

Many people consider geology as a static resource with extreme time scales that have no bearing on present decision-making and planning. Other people realize the significance of considering geology and its importance to everyday life, current decision making, and planning. The National Park Service is beginning to view and manage geologic resources as dynamic. Increasingly, park managers are integrating geologic resource information and considerations into the broader context of park management.

Ecosystem management is holistic and requires an understanding and integration of biological and social components, as well as an understanding of the physical setting, including geology (Hughes et al., 1999). An area's geologic setting and physical processes affect both landforms and natural vegetation, which in turn influence the distribution of habitats. Many changes to ecosystems—including geologic processes—can be traced directly to human alteration of the physical environment.

The following sections of this introduction provide information about the intent of the GPRA goal, geology's role in the ecosystem, and the park's setting, resources, and geology.

1.1 GPRA Goal Background

In 1999, the Geologic Resources Division (GRD) and the NPS Strategic Planning Office cooperated to develop a Servicewide geologic resource goal as part of the Government Performance and Results Act (GPRA). The NPS Goal Ib4 states, "Geological processes in 53 parks [20% of 265 natural resource parks] are inventoried and human influences that affect those processes are identified." This goal is a knowledge-based goal designed to improve park capabilities to make more informed science-based management decisions. This goal was intended to be the first step in a process that would eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features, or cause critical imbalance in ecosystems.

1.2 Park Selection

Cape Cod National Seashore was selected as one of the parks to be assessed for GPRA Goal Ib4 primarily because of its geologic resources and human use. Since the GPRA goal includes only 20% of the parks, information gathered at this park may also be used to represent other parks with similar resources or patterns of use, especially when findings are evaluated for Servicewide implications. In addition, Cape Cod National Seashore is one of ten Long Term Ecological Monitoring Pilot Parks, a designation established prior to the Natural Resource Challenge. This designation and history puts Cape Cod National Seashore in a unique position among parks because much baseline information has already been gathered throughout the past decade.

In light of the previously run field trip, during which most participants had the opportunity to meet one another and discuss issues facing the park, the execution of a conference call made sense. It was an efficient and cost-effective outcome. It also provided the NPS Geologic Resources Division the opportunity to test the concept of a conference call serving as a scoping meeting with participants who were already “primed” for the session.

1.3 Geology’s Role in the Ecosystem

The geologic resources of a park—soils, caves, fossils, streams, springs, beaches, volcanoes, etc.—provide the physical foundation required to sustain the biological system. Interference with geologic processes and alteration of geologic features inevitably affect habitat conditions. For example, channelization of the Virgin River in Zion National Park caused the channel to incise, lowering the groundwater table and reducing the habitat of flood plain obligate species (Steen, 1999). For a more detailed discussion of geologic processes and their roles in ecosystems, see Appendix 1 and Appendix 4.

1.4 Geoindicators Background

It may be difficult in an ecosystem to separate the human influences from the geologic ones. To assist in this task, the geoindicators were introduced to NPS resource managers as a new ecosystem management tool for park planning in 2000. The basic geoindicators tool is a compiled checklist of geological indicators that record rapid change in the physical environment. These indicators, developed by the International Union of Geological Sciences, provide a science-based method to assess rapid changes in the entire ecosystem. The list includes 27 earth system processes and phenomena that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions (Appendix 3).

Geoindicators measure both catastrophic events and those that are more gradual still but evident within a human life span. The NPS uses the geoindicators concept as the basis for discussing and evaluating the state of the environment, ecosystem changes, and how humans are affecting natural systems in selected national parks. Geoindicators are an invaluable tool to help focus non-geoscientists on key geologic issues, help park managers anticipate what changes might occur in the future, and identify potential management concerns from a geological perspective.

The NPS uses geoindicators as a proxy for geologic processes. Geoindicators are not geologic processes; however, there is a strong correlation between the two (Appendix 4). Since geoindicators represent a landscape measurement—one that concentrates on physical processes and their interactions with biologic and human components—they are uniquely suited to assess human vs. natural causes of change in an ecosystem.

1.5 Cape Cod National Seashore's Setting and Resources

Cape Cod National Seashore comprises 43,604 acres of shoreline and upland landscape features, including a 40-mile-long stretch of pristine beach; 20 clear, deep, freshwater kettle ponds; and upland scenes that depict evidence of how people have used the land. A variety of historic structures are within the boundary of the Seashore: lighthouses, a lifesaving station, and numerous Cape Cod style houses. The Seashore offers six swimming beaches, 11 self-guiding nature trails, and a variety of picnic areas and scenic overlooks.

Cape Cod National Seashore was established after the area had been settled for more than 300 years. In the Provincetown area, visitors can see where the Pilgrims landed in 1620 before sailing across the bay to Plymouth. The manner and timing of the National Seashore's creation (in 1961) has resulted in great challenges for park managers. There is an ongoing process of respecting historical jurisdiction and practices in ways that preserve the mandate of the National Seashore.

In the past 30 years, the Cape's permanent population has increased from 70,000 to 190,000, a figure that nearly triples during the peak summer season (Finch, 1997). Since the National Seashore is neither wilderness nor exclusively recreational, the park must be managed as a responsible combination of the two, optimizing both needs within a context of increasing popularity.

1.6 Cape Cod National Seashore's Geologic Setting

Cape Cod resembles a flexed arm of sand thrust out into the Atlantic Ocean. It owes its origin to glaciers, which were active in the area as recently as 14,000 years ago. Since that time, waves and nearshore currents have extensively reshaped the sedimentary deposits left by these glaciers into a variety of coastal environments, for example, sandy beaches flanked by towering sea cliffs and bluffs and discontinuous chains of barrier islands, many with elegantly curved sand spits. Remarkably, the 40-mile-long eastern coastline of Cape Cod, despite its proximity to Boston, possesses few shore-protection structures; it is the longest, pristine shoreline of sand in New England (Pinet, 1992).

About 15,300 years ago, a huge ice sheet, which flowed southward from Canada, covered all of New England. As the ice mass crept across the continental shelf, one of its ice lobes—the Cape Cod Bay Lobe—deposited sediment at its margin and formed a morainal ridge—the terminal moraine—that can now be traced across Martha's Vineyard and Nantucket, the two principal islands south of the Cape. In addition to the terminal moraine, recessional moraines also indicate the presence of the former ice sheet in southeastern Massachusetts. As the ice sheet retreated northward, meltwater trapped by the recessional moraine formed Glacial Lake Cape Cod. Stratified muds, silts, and deltaic sands accumulated in this glacial lake, which covered an area amounting to about 400 square miles. A river outlet cutting into the recessional moraine drained water out of the lake, presumably in the area of Eastham and Town Cove section of Nauset Beach. The South Channel lobe was just to the east, and its meltwater carried huge quantities of sediment from the glacier. This sediment formed the gently sloping (towards the west) outwash plains that are several miles long and now comprise much of the Outer Cape.

When the ice sheet disappeared, the landforms of the Cape looked quite different than they do today. As the ice melted, sea level rose and flooded the area. Paleogeographic reconstructions of the shoreline indicate it was quite irregular at that time—a series of headlands and embayments composed of unconsolidated glacial sediments (glacial drift). This original coastline was located as much as three miles seaward of the present shoreline. Since then, sediment redistribution by waves and nearshore currents has changed the morphology of the landforms.

Landscapes change quickly in Cape Cod, and the retreat of the ice sheet is no exception, taking less than 3,000 years. Likewise, the creation of landforms after glacial retreat happened quickly, some taking as little as several hundred years. Outwash plain deposits, which are commonly pocked and pitted by kettle holes (e.g., the Wellfleet pitted outwash plain), are the major geologic feature of the lower Cape. When the kettles are deep enough to intersect the water table, a pond is formed. Pond level provides a close approximation of groundwater level.

The encroachment of the sea following deglaciation permitted wave currents to erode and rework the glacial drift. As waves refracted, energy was focused on the headlands. Consequently, peaks of land were worn down by wave erosion, creating a system of steep, wave-cut cliffs. The sediment moved by nearshore currents sequentially formed a series of sand spits and barrier islands (Uchupi et al., 1996). Prior to 6,000 years ago, the longshore drift of sand was predominantly to the south. This prevailing pattern of sediment movement formed the southern barrier island system of Nauset Spit, and eventually, Monomoy Island. The crest of Georges Bank, far offshore, still stood above sea level and afforded the northern shoreline of the Cape protection from erosion by large ocean waves approaching from the southeast. About 6,000 years ago, however, the rising sea submerged Georges Bank, exposing the Cape to wave attack from the southeast, resulting in the northerly transport of sand that eventually formed the curved spit system of Province Lands surrounding Provincetown. The appearance of the spit sheltered the northern shoreline and resulted in a northward transport direction on the bayside, whereas further south littoral transport was directed southward along Cape Cod Bay.

Erosion of the glacial deposits produced imposing marine cliffs, many of which are currently retreating at alarming rates. Although scarp retreat of the eastern shoreline averages 0.67 m/yr, specific coastal sites are losing land to the sea at higher rates. For example, the cliffs below Wellfleet-by-the-Sea are retreating approximately 1.0 m/yr (Pinet, 1992). Because most of this erosion occurs during storm events, cliff retreat is not constant over time.

A summary of Cape Cod's geology is not complete without mention of sand dunes. This feature epitomizes Cape Cod itself—migrating constantly yet somehow enduring. Dunes are shaped by the prevailing winds and migrate constantly. On the Provincetown spit, there are parabolic dunes, or "U" shaped dunes, with the open end facing the wind. These are formed when the wind blows away the sand in the middle of the dune, exposing the underlying beach deposits. The eroded sand is transported by the wind and deposited along the advancing leeward face of the dunes (Oldale, 1998). The parabolic dune orientation is driven by strong winds from the northwest predominantly in the winter, but occasionally important in the summer (Allen et al., 2001).

Active coastal dunes are dynamic landforms whose shape and location are ever-changing. Youthful, unvegetated dunes are on the move as the sand, exposed to the prevailing wind, is picked up, transported, and redeposited repeatedly. When the dunes become vegetated, they stabilize and tend to remain unchanged for a time. If the dunes lose the protective vegetation, they will move again. This can be seen along US Route 6 in Provincetown, where once stable dunes are advancing on the forest and highway and are filling Pilgrim Lake (Oldale, 1998).

2.0 Results of Geoindicators Scoping Meeting

A geoindicators scoping meeting for Cape Cod National Seashore was executed in the form of a three-hour conference call on March 11, 2002. The purpose of the scoping session was to determine the significant geologic processes that shape Cape Cod National Seashore's ecosystems and identify the human influences on those processes.

Table 1 lists the geoindicators identified at Cape Cod National Seashore. These geoindicators were adapted from Berger (1995) and are considered a proxy for geologic processes. For each geoindicator, the group rated the significance of the geoindicator in the ecosystem, the degree of human influence on the geoindicator, and the significance to park management. A rating of high, medium, or low was used. In two cases—soil quality and slope failure—the rating of human impact was "split" to emphasize a past-present or a regional-local dichotomy respectively.

The scoping group identified 19 geologic processes that are present in Cape Cod National Seashore. Fourteen of the geologic processes are considered to be highly significant to the ecosystems. Although the group decided to not eliminate one of the geoindicators, surface temperature regime, from the Cape Cod list, it was not rated because the participants did not know enough about the issues and processes related to this indicator to satisfactorily rate it.

Human influences on the National Seashore include activities related to visitors and permanent residents, NPS administrative practices, and adjacent land managers' practices. It was determined at the outset of the discussion that the most beneficial evaluation must include all of Cape Cod, not just the area within the National Seashore's boundaries. Human influence on geologic processes was ranked high for 12 of the 19 geoindicators (63%).

Geologic processes may have high management significance because of juxtaposition to popular visitor areas, safety concerns, aerial extent, administrative use of resources, or protection of fragile resources from detrimental human activities. Management significance was high for 12 geoindicators: shoreline position, relative sea level, wind erosion, all of the groundwater geoindicators, all of the surface water geoindicators except stream channel morphology (which was rated medium), and slope failure. Dune formation and reactivation, the soils geoindicators, surface displacement, and sediment sequence and composition were rated low.

Nine geoindicators were rated high for all three categories: importance to park's ecosystem, human impact on the geologic process, and significance to park management. The three groundwater geoindicators were considered particularly significant for the health of the Cape Cod ecosystem. Shoreline position, surface water quality, wetlands, streamflow, stream sediment storage and load, and slope failure (with respect to human impacts on a local scale) were also given high ratings in all three categories.

Table 1. GPRA Ib4 Data Set for Cape Cod National Seashore
Relative importance of the natural process, degree of human influence, and management significance of selected geoindicators at Cape Cod National Seashore.

Geoindicators Identified in the Ecosystem	**How important is the process to the park's ecosystem?**	**Rank the human impact on the geologic process**	**Significance to park management**
COASTAL			
1. Shoreline position	H	H	H
2. Relative sea level	H	L	H
3. Dune formation and reactivation	H	H	L
4. Wind erosion	H	L	H
GROUNDWATER			
5. Groundwater quality	H	H	H
6. Groundwater chemistry in the unsaturated zone	H	H	H
7. Groundwater level	H	H	H
SURFACE WATER			
8. Surface water quality	H	H	H
9. Lake levels and salinity	H	L	H
10. Wetlands extent, structure, hydrology	H	H	H
11. Streamflow	H	H	H
12. Stream channel morphology	M	H	M
13. Stream sediment storage and load	H	H	H
SOILS			
14. Soil quality	M	*H/L	L
15. Soil and sediment erosion	L	M	L
HAZARDS			
16. Slope failure (landslides)	H	**L/H	H
17. Surface displacement	L	L	L
SURFICIAL FACTORS			
18. Sediment sequence and composition	H	L	L
19. Subsurface temperature regime	?	?	?

*High with respect to past practices, Low with respect to present practices.
**Low on a regional scale, High on a local scale.

2.1 Coastal Geoindicators

<u>*Shoreline Position*</u>
Ecological Importance: High
Human Impact: High
Management Significance: High

There is no doubt that shoreline position is a useful geoindicator for Cape Cod National Seashore, since coastal processes drive all upland features and are fundamental to other environmental changes. For example, these processes control the formation of small barrier beaches on the bay side that in turn influence and protect salt marshes and wetlands and their biotic habitats. Coastal processes are also important on the Atlantic side at Pleasant Bay and Nauset Marsh.

The coastal processes that drive shoreline position influence slope failure [see the slope failure (landslide) geoindicator discussion], which impacts parking lots, roads, and lighthouses. Hence, there is a strong economic and aesthetic component to this geoindicator; it directly affects infrastructure and cultural resources in the National Seashore.

There is relatively unimpeded flow of sediment along the coast of Cape Cod National Seashore, since the shoreline is devoid of significant engineering structures at inlets and only the asphalt revetment [at Herring Cove Beach] has an effect on shoreline change. Moreover, the revetment is small, less than 50 m, and is located on the relatively low energy bayside (Allen et al., 2001). Other revetments occur along Nauset Marsh, Pleasant Bay, and Wellfleet Bay. Outside the National Seashore's boundaries, there is a seawall line at Provincetown Harbor, jetties and dredging at the mouth of the Pamet River, and dredging at McMilliam Wharf (Provincetown) and Aunt Lydia's Cove (Chatham).

In addition, Pilgrim Lake within the National Seashore's boundaries is a former tidal lagoon, cut off from tidal flow when a dike was constructed originally to allow a railroad to pass and now allows Highway 6 to pass. The lack of saltwater flow has decreased the salinity levels and turned the bay into a lake. Park management currently refers to Pilgrim Lake as "East Harbor," which expresses the awareness of this impact and the desire to return it to its natural system. The flapper valve of the 700-feet-long culvert leading into East Harbor was recently secured open to allow saltwater to flow into the lake. Salinity levels reached 17 ppt during this test. In order to allow alewife spawning, park management closed the flapper valve in February 2002. The U.S. Army Corps of Engineers is interested in conducting a feasibility study of returning the brackish lake to a saline back-barrier lagoon.

With a permanent population of 190,000 (and rising) and a steady stream of day visitors, another type of human impact affecting the shoreline change is obviously human traffic. Foot traffic by visitors accessing and recreating on the beaches tramples the sand, creates informal trails, and causes unnatural erosion. Extensive off-road-vehicle (ORV) use impacts the shoreline position as well.

An example of human influence on shoreline position was highlighted during the scoping session. Some years ago, fencing was installed at an overwash at Ballston Beach to control erosion. This fencing acts to control pedestrian traffic and promote accretion of sand. As the elevation of the overwash deposits have risen, the probability of future overwash events is believed to have decreased. The Pamet River system has been identified as a very complex and highly altered system; therefore, it is recommended that research studies be executed to better understand and quantify the human influences on the geologic processes that operate within the system. Future management actions at this site will be considered within a comprehensive management plan for the Pamet River system that takes into account the restriction to tidal influence at the north end and other historical alterations. The information from such a study would be useful for park planning and decision making.

Shoreline position is monitored semi-annually at Cape Cod National Seashore using ground-based Global Positioning System (GPS) surveys of the wet/dry line and the SWASH (Surveying Wide Area Shorelines) system (Allen, 2001; List, 2001). SWASH is a vehicle-based system that utilizes recent advances in GPS. Shoreline change studies have focused on long- to short-term changes.

A current study that focuses on event-scale (individual storms) is referred to as "hotspot research" and is important for understanding the shoreline position in Cape Cod National Seashore. While studying short-term impacts of storms, it was found that the shoreline erosion response was extraordinarily non-uniform, with zones of significant erosion (more than 20 m of shoreline recession) alternating with zones of virtual stability (less than 2 m of change). In periods of decreasing waves following a storm, the pattern of change nearly reversed, with the erosion zones showing strong accretion and the stable zones still exhibiting no significant change. Although the processes responsible for these erosional "hotspots" are unknown, their identification has important implications for park management (List, 2001).

Research in other locations (New York and North Carolina) suggests that erosional hotspots are related to shallow geology, which dictates sediment availability and bathymetry. There are no such data for Cape Cod National Seashore. Additional research, including mapping of the offshore geologic framework, is needed at Cape Cod National Seashore to better understand the cause or causes of erosional hotspots (R. Thieler, personal communication, 3/13/02). Until the cause or causes are understood, park management cannot anticipate the effects of hotspots on park resources through time.

As population density in Cape Cod increases, coastal erosion is becoming a critical problem. Additional information is needed to improve our fundamental understanding of storm-induced coastal erosion on a large scale (order: tens of kilometers). The state of Massachusetts performs post-hurricane aerial photography—most recently after Hurricane Bob (1989), and coastal erosion research is a primary component of the U.S. Geological Survey's Coastal and Marine Program. A combination of SWASH and LIDAR is recommended at present, although updated technologies may improve upon these survey techniques. Repeated shoreline surveys using SWASH provide quantitative data for verifying laser technology for aerial topographic surveying (LIDAR). A monitoring program that uses LIDAR and SWASH will facilitate a comparison between methodologies for determining shoreline position.

Relative Sea Level
Ecological Importance: High
Human Impact: Low
Management Significance: High

Changes in Relative Sea Level (RSL) may alter the position and morphology of coastlines, causing coastal flooding, water-logging of soils, and a loss or gain of land. They may also create or destroy coastal wetlands and salt marshes, inundate coastal settlements, and induce saltwater intrusion into aquifers, leading to salination of groundwater. Coastal ecosystems are bound to be affected, for example, by increased salt stress on plants. A changing RSL may also have profound effects on coastal structures and communities. Low-lying coastal and island states are particularly susceptible to sea-level-rise. It is estimated that 70% of the world's sandy beaches are affected by coastal erosion induced by RSL rise. For these reasons, this geoindicator was rated highly important to the ecosystem and for management significance in Cape Cod National Seashore.

Although the human impact on this geoindicator was determined to be low—since practices such as ditching and diking no longer occur in Cape Cod National Seashore—it that ditching and diking of formerly tidal wetlands has caused significant subsidence within the National Seashore, and is, therefore, important with respect to sensitivity of the habitats affected and the challenge subsidence poses to restoration efforts (C. Phillips, personal communication, April 2002).

A pressing question for Cape Cod is whether the marshes can keep up with sea-level rise. Cape Cod's fresh groundwater rests on seawater and necessarily rises along with sea level; therefore, the diked Pamet marsh, for example, continues to rise along with groundwater levels, but in a way that is very different from the way salt marshes normally grow. Salt marshes typically keep pace with sea-level-rise largely through the accumulation of inorganic sediment, i.e., sand, silt, and clay. The diked upper Pamet has been denied this sediment supply for over 100 years and has subsided as peat has dried out. In the meantime, any accretion has been through the production of organic matter (Portnoy, 1999).

Although monitoring of wetlands has been a useful proxy for sea-level-rise in Cape Cod National Seashore, it has been the response to relative sea level rise that has been studied. Monitoring of relative sea level is needed to assess the direct impacts on park resources. The closest monitoring is done in Woods Hole and Boston Harbor. The participants suggested a monitoring station in the Provincetown or Nauset Marsh areas.

Dune Formation and Reactivation
Ecological Importance: High
Human Impact: High
Management Significance: Low

Coastal dunes are important determinants of coastal stability because they supply, store, and receive sand blown from adjacent beaches. Moving dunes may engulf houses, fields, settlements, and transportation corridors. Dunes play an important role in many ecosystems (boreal, semi-arid, desert, coastal) by providing morphological and hydrological controls on biological gradients. Widespread changes can also be induced by changes in wind patterns and by human disturbance, such as alteration of beach processes and sediment budgets, destruction of vegetation cover by trampling or vehicle use, overgrazing, and the introduction of exotic species.

Dune formation is considered a highly important geoindicator with respect to Cape Cod's ecosystems and human impacts, namely because of the aerial extent of the dunes; they cover the entire northern portion of the Cape, and there are extensive dune fields in the south, which are now in overwash mode.

Historical impacts on dune formation include grazing, extensive deforestation, and subsequent revegetation efforts. Since the 19th century, migration of the dunes has caused alarm. Dunes have migrated into Pilgrim Lake, over homes in Provincetown, and onto roads. In the 1980s, mitigation efforts were seen as a top priority, and funding was spent on efforts such as pouring asphalt onto the dunes and revegetating the dunes. In general, mitigation of dune migration has grown out of the spotlight recently, and although sand dunes are an important resource, mitigation efforts are not being employed by the current administration; hence, the ranking of low in the management significance category. If the historic dune shacks were to become threatened by dune migration, park management would consider stabilizing the dunes in these areas.

Baseline information for dune formation was deemed to be lacking, although a chronology of dune movement has been established (Winkler, 1992; Madore and Leatherman, 1981; Madore and Anders, 1981). An overall assessment of the dune sediment budget is recommended to determine whether there is a need for detailed calculations of sand volume. LIDAR can be used for studies of the sediment budget of dunes in Cape Cod National Seashore. Work relating to the dune-formation geoindicator, i.e., research and mapping of dune swales in the Province Lands, has been initiated (C. Phillips, personal communication, 4/17/02).

Wind Erosion

Ecological Importance:	High
Human Impact:	Low
Management Significance:	High

The action of wind on exposed sediments and friable rock formations causes erosion and entrainment of sediment and soil particles, as well as forms and shapes sand dunes and other landforms. Wind can reduce vegetation and expose subsurface deposits and plant roots. Wind erosion is a natural phenomenon, but the surfaces upon which it acts may be made more susceptible to wind erosion by human actions that result in the reduction of vegetative cover.

Wind erosion of sediment occurs in only limited areas of the park, but it is of high management significance because of the degradation of popular areas, such as Herring Cove. Aerial photographs revealed a "spider web" of social trails in this area. This uncontrolled foot traffic destroys vegetation thus exposing surface sands to the effects of wind. The Park is considering monitoring the proliferation of social trails at Herring Cove and other areas of concern.

2.2 Groundwater Geoindicators

<u>Groundwater Quality</u>
Ecological Importance: High
Human Impact: High
Management Significance: High

On a global scale, both humans and animals consume groundwater; hence, changes in groundwater quality can have serious consequences. Groundwater is also responsible for maintaining many habitats and for maintaining the quality of baseflow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, industrial use, and other purposes. It also influences ecosystem health and function, so that it is important to detect change and early warnings of change both in natural systems and resulting from pollution.

Groundwater is an extremely important issue in Cape Cod National Seashore with respect to the ecosystem, human impacts, and management. The majority of available fresh water on the lower Cape is groundwater. On the lower Cape, all groundwater has local precipitation as its source (Water Resources Management Plan for Cape Cod National Seashore, 1999). The groundwater resource directly supports most of the lower Cape's surface water—ponds, streams, and fresh water wetlands. The human populations of the lower Cape are also entirely dependent on the groundwater for private and municipal water supply (Water Resources Management Plan for Cape Cod National Seashore, 1999). For this reason, the U.S. Environmental Protection Agency has designated this water source a "sole source aquifer" and must review any federally funded projects within the aquifer's watershed. The sole source designation is granted on the basis of a water supply source being needed to supply greater than 50% of the drinking water to its service area where there is no reasonable alternative should the source become contaminated (Massachusetts Department of Environmental Management, 1994).

Growing population and housing density in lower-Cape communities have increased demand and simultaneously degraded local groundwater quality to the extent that some communities are considering new public supply well locations. Since the National Seashore occupies a large percentage of the lower Cape land area and contains protected open space, National Seashore lands are often viewed as prime sites for withdrawing high quality drinking water. It is a delicate issue to balance water supply needs against a park mandate to protect all natural resources, including the groundwater resources vital to maintaining surface water ecosystems (Water Resources Management Plan for Cape Cod National Seashore, 1999).

The public views Cape Cod National Seashore as being the source of needed groundwater. Pumping of groundwater for public use on an emergency basis is permitted at two wells in the National Seashore. Provincetown has been granted a short term, emergency special-use permit, which requires that the town show a zero-growth rate, educate their residents about water conservation, and actively evaluate other water sources. Provincetown works collaboratively with the National Park Service on educating its citizens about water conservation, and the town has taken the lead among surrounding towns in water conservation. The National Park Service fills a critical role as educator by modeling water conservation [and water quality] strategies at the National Seashore.

<u>*Groundwater Chemistry in the Unsaturated Zone*</u>
Ecological Importance: High
Human Impact: High
Management Significance: High

The unsaturated zone may store and transmit pollutants, the release of which may have a sudden adverse impact on groundwater quality. Depending on land use, the unsaturated zone beneath a site may record either natural inputs from the atmosphere, vegetation, soil or mineral weathering, or the effects of human activities, such as agriculture and industrial activity, or regional problems such as acid deposition.

Like groundwater quality, groundwater chemistry in the unsaturated zone has high significance (in all categories) for Cape Cod National Seashore. Groundwater on the Cape is withdrawn from shallow sand and gravel aquifers that are susceptible to contamination from anthropogenic sources (Oldale, 1992). The generally shallow depth to the water table minimizes the time and distance required for contaminants to reach the groundwater (Water Resources Management Plan for Cape Cod National Seashore, 1999).

The lower Cape is largely without a sewer system, relying on private septic systems that recycle wastewater back to the groundwater, which creates problems of nutrient loading and nitrate contamination (Water Resources Management Plan for Cape Cod National Seashore, 1999). Various reports have documented increases in nitrate concentrations in the groundwater on the outer Cape and have directly linked the elevated levels with increases in housing density and the number of actively used on-site septic systems (Frimpter and Gay, 1979; Persky, 1986; Noss, 1989, Goetz et al., 1991; Sobczak and Cambareri, 1995). In 1996, the septic system at the Salt Pond Visitor's Center was declared "failed" and a new septic system was designed and went online in 1998 (Water Resources Management Plan for Cape Cod National Seashore, 1999). As part of the Visitors Center renovation, a new system is planned that will remove additional nitrogen from wastewater before discharge to the unsaturated zone (J. Portnoy, personal communication, 4/01/02).

There are four inactive landfills on the lower Cape (Truro, Wellfleet, Eastham, and Orleans), and one capped landfill in Provincetown. Both Provincetown and Truro landfills are located within the National Seashore boundaries and have contamination plumes emanating from their containment areas (Urish et al., 1993; Cambareri et al., 1989; Frolich, 1991). The Wellfleet landfill abuts the National Seashore boundary and has a plume that travels southwest toward the Herring River (Water Resources Management Plan for Cape Cod National Seashore, 1999). Resource managers are working with the U.S. Geological Survey to study landfill contamination flows and impacts.

Underground storage tanks also pose a threat to groundwater in Cape Cod. Barnstable County has a record of all active underground storage tanks (UST) in the towns surrounding the National Seashore. The majority of tanks hold fuel oil and range in size from 200 to 2,000 gallons. Each town on the lower Cape has regulations for UST that outlines an inspection and permitting program (Water Resources Management Plan for Cape Cod National Seashore, 1999). Leaks in underground storage tanks have occurred in Cape Cod National Seashore, for example, a UST owned by Jack's Gas (1998). The fiberglass tank cracked during installation and released gas for two years before detection (N. Finley, personal communication, 4/26/02). Another pollutant related to petroleum is MTBE, which is also a concern for groundwater in Cape Cod National Seashore.

Groundwater Level
Ecological Importance: High
Human Impact: High
Management Significance: High

Groundwater is the major source of water in many regions, supplying a large proportion of water globally. In the United States, more than half the drinking water comes from the subsurface, and in many regions, it is the only source of water. The availability of clean water is of fundamental importance to the sustainability of life. It is essential to know how long the resource will last and to determine the present recharge, given that groundwater extraction at a rate that exceeds recharge is not a sustainable practice.

There are natural changes in groundwater levels because of climate change (e.g., drought), but the main changes are due to human extraction. Both of these factors are playing recognizable roles in Cape Cod's ecosystem. On the lower Cape, all groundwater has precipitation as its source, and the lack of precipitation during recent drought conditions is lowering the groundwater table. In addition, an increasing population is using more water. Summer months show the greatest impact on groundwater levels with peak drawdown in August.

Large-scale groundwater withdrawals change the local water balance and the rate and pattern of groundwater flow, resulting in impacts to the groundwater dependent ecosystems (Martin, 1993). There are three primary groundwater withdrawal concerns facing the National Seashore as development continues and the demand for new private and public water wells increases. First, excessive groundwater withdrawals can lower the local water table, potentially depleting pond, wetland, and vernal pool water levels. Second, large-scale, sustained pumping can decrease aquifer discharge, impacting streams and estuaries. Finally, under extreme cases, the groundwater volume may be depleted to a point where salt water intrudes and contaminates the fresh groundwater (Sobczak and Cambareri, 1995). The combination of an extremely vulnerable sole source water supply and the rapid growth on the lower Cape makes for a serious situation and requires a comprehensive resource protection and management program (Zoto, 1988).

2.3 Surface Water Geoindicators

Surface Water Quality
Ecological Importance: High
Human Impact: High
Management Significance: High

Surface water quality is highly important to the ecosystems in Cape Cod National Seashore, since clean water is essential to all living organisms. Interactions with soil, transported solids (organics, sediments), rocks, groundwater, the atmosphere, and biota determine the water quality of a lake, river, pond, or wetland. It can vary in space and time with respect to natural geomorphological (e.g., erosion rates), hydrological, chemical, and biological changes. Surface water quality may also be significantly affected by agricultural, industrial, urban, and other human actions, as well as by atmospheric inputs. Pollution of natural bodies of surface water is widespread globally because of human activities, such as disposal of sewage and industrial wastes, land clearance, deforestation, use of pesticides, mining activities, and hydroelectric developments. The bulk of the solutes in surface waters, however, are derived from soils and groundwater baseflow.

Surface water quality has high management significance for Cape Cod National Seashore and has been highly impacted by human activities. Inorganic and organic pollutants derived from landfills, leaking underground storage tanks, septic effluent, and urban runoff on the lower Cape pose a serious threat to clean drinking water and to ponds, rivers, and estuaries located within the National Seashore. The intimate connection between the Cape's groundwater and surface water compounds the difficulty of managing these problems, as does the permeability and generally poor contaminant absorption characteristics of the region's sand and gravel aquifer. There are five landfills located on the lower Cape, all of which have the potential to impact the freshwater resources within the National Seashore. According to past research reports, some surface water both inside and outside the National Seashore may have already been degraded (Cambareri et al., 1989; Frolich, 1991; Urish et al., 1993; Winkler, 1994).

Nearly all of the 20 kettle ponds located within the National Seashore's boundaries are used for recreation. Many of the ponds are accessible by car, making them a target for visitation. Heavy public use of many kettle pond shorelines has caused soil erosion and sediment deposition. Every pond used for recreation, such as swimming and fishing, is experiencing sediment deposition because of erosion of roads, trails, and shorelines. More data need to be gathered to quantify recreation uses and the effects on pond water quality, in general, and soil erosion and sediment deposition in and around ponds, specifically. Shoreline erosion and historic fisheries management, including stocking and liming, have affected pond waters. There are 20 years of data regarding the ponds in Cape Code National Seashore. The "pond atlas" synthesizes these data (Portnoy et al., 2001).

While many pond management issues are obvious, management authority is not. There are several agencies and many landowners that have some control over access and management. A coordinated system for multi-jurisdictional management has not yet been established.

It is estimated that Cape Cod National Seashore has a moderate to high risk for a major oil spill, primarily because of ship traffic in and out of Boston. The Seashore has experienced only small spills. There have been occurrences of tar balls on beaches and oil/gas discharge from small boats. Seashore managers recognize the potential for a major spill and have an oil spill contingency plan that is coordinated with local contingency plans.

Lake Levels and Salinity
Ecological Importance: High
Human Impact: Low
Management Significance: High

Lakes and ponds in Cape Cod National Seashore, are dynamic systems that are sensitive to local climate and to land-use changes in the surrounding landscape. In general lakes receive their water mainly from precipitation, and some are dominated by drainage runoff. In Cape Cod National Seashore, kettle ponds are controlled by groundwater systems. The aerial extent and depth of water in lakes are indicators of changes in climatic parameters such as precipitation, radiation, temperature, and wind speed. Where not directly affected by human actions, lake level fluctuations are excellent indicators of drought conditions. Kettle ponds can also be valuable indicators of near surface groundwater conditions.

In general, there have been minimal human impacts on the pond levels in Cape Cod National Seashore; hence, the rating of low in this category. Changes in pond levels appear to be largely natural. Modeling shows that development of wells will impact pond levels, and Cape Cod National Seashore has a good monitoring program in place. Siphon gauges are used to measure pond levels. Park managers either have adequate information to answer questions being raised, or have the capability "in house" to pursue unanswered questions.

Wetlands Extent, Structure, and Hydrology
Ecological Importance: High
Human Impact: High
Management Significance: High

Wetlands are areas of high biological productivity and diversity. They provide important sites for wildlife habitat and human recreation. Wetlands affect local hydrology by acting as a filter—sequestering and storing heavy metals and other pollutants. Wetlands act as carbon sinks—storing organic carbon in waterlogged sediments. They can also be carbon sources, when carbon is released via degassing during decay processes or after drainage and cutting, as a result of oxidation or burning. Globally, peatlands have shifted over the past two centuries from sinks to sources of carbon, largely because of human exploitation (i.e., drainage, aeration, and consequently increases rates of decomposition).

Park managers consider wetlands to be of high ecological importance in Cape Cod National Seashore because of the diversity of types (bogs, salt marshes, vernal ponds, kettle ponds, streams, deflation plains), significant aerial extent, and important ecological functions. Fifty percent of the diked marshes on Cape Cod are within the National Seashore, and considerable ditching was done in the past for mosquito control. The current administration at Cape Cod National Seashore has made restoration of wetlands to their natural function a priority.

Wetlands develop naturally in response to morphological and hydrological features of the landscape. Their evolution can be affected by external factors such as climate change, landscape processes (e.g., coastal erosion), or human activity (e.g., draining, channeling of local rivers, water extraction and impoundment, and forest clearance). For instance, diking and drainage in the late 19th century and freshwater impoundment in the mid-20th century have interrupted the evolution of salt marshes in the upper Pamet River. These hydrologic alterations have caused vegetation to shift from salt-tolerant grasses to salt-intolerant herbs, trees, and shrubs and have caused the wetland surface to subside well below the elevation of modern, undiked marshes. Former estuarine wetlands associated with the Hatches Harbor, East Harbor, and Herring River systems have been similarly affected by diking. Efforts to restore tidal influence and estuarine function are ongoing at Hatches Harbor and East Harbor; park managers hope to expand these efforts to the Herring River system as well.

In addition, the Pamet system should be evaluated using recent hydrologic, hydrographic, and ecological research to work toward restoring the dynamic equilibrium between the Pamet wetlands and modern sea level. A phased reintroduction of normal tidal flow from Cape Cod Bay would allow for a gradual transition.

<u>*Streamflow*</u>

Ecological Importance:	High
Human Impact:	High
Management Significance:	High

Participants discussed changing the title of the geoindicator from “stream” to “estuarine” in order to more fully capture the dynamics operating in Cape Cod National Seashore. An international Working Group of the International Union of Geological Sciences (IUGS) developed geoindicators, and the National Park Services has adapted the tool for addressing human influences on geologic processes. It is beyond the scope of this scoping session to change the geoindicator itself; nevertheless, the difference has been identified and should be kept in mind with respect to the dynamics of “streamflow” within Cape Cod National Seashore. Streamlevel and discharge is affected by tidal stage. Inflow is both freshwater and saltwater, i.e., estuarine. The freshwater influx is from groundwater discharge. It should be noted that the controlling processes, sediment dynamics, and hydrodynamics are radically different in estuaries, particularly the tidal creeks, than in streams.

This geoindicator is important because streams respond rapidly to changes in an ecosystem. Streamflow directly reflects climatic variation. Stream systems play a key role in the regulation and maintenance of biodiversity. Changes in streams and streamflow are indicators of changes in basin dynamics and land use. Streamflow is considered an important geoindicator for Cape Cod’s ecosystem because of the aerial extent and unique and sensitive ecology of these systems. Take, for example, the extent of area covered by the Pamet and Herring river systems. Streamflow also has a direct link to marshes (see wetlands discussion).

Natural variations in streamflow predominate, but streams have been strongly modified by human actions in Cape Cod National Seashore. Most significant is the fact that about 40% of these systems have had restricted flow (i.e, dikes) because of human intervention (this represents over half of the tidal-restricted marshes Cape-wide). This geoindicator is of high management significance, and there are good baseline data and models for these estuarine systems.

Stream Channel Morphology
Ecological Importance: Moderate
Human Impact: High
Management Significance: Moderate

The stream channel morphology and streamflow geoindicators go hand-in-hand in Cape Cod National Seashore. Channel dimensions reflect the magnitude of water and sediment discharges. In the absence of hydrologic and streamflow records, an understanding of stream morphology can help delineate environmental changes of many kinds. The significance of this geoindicator is considered moderate for Cape Cod National Seashore, as is the significance to park management.

Human impacts of stream channel morphology have had a long history and are considered of high significance in Cape Cod National Seashore. Although many past practices—channeling, ditching, dewatering, and vegetation cutting—are no longer permitted within the Seashore, park managers must make decisions with the understanding that impacts from past activities are still present. An example of this is the Herring River, which was channeled annually until 1984. Park managers are not actively mitigating past channelization, but are allowing natural restoration to occur.

Mosquito control methods are still practiced outside of the National Seashore's boundaries and in portions of the Province Lands. Drainage to reduce mosquito-breeding sites has led to the production of acid sulfate soil, fish kills, and exotic plant infiltration.

Stream Sediment Storage and Load
Ecological Importance: High
Human Impact: High
Management Significance: High

Sediment load determines a stream's channel shape and pattern; hence, this geoindicator is directly linked to stream channel morphology. Changes in sediment yield reflect changes in basin conditions, including climate, soils, erosion rates, vegetation, topography, and land use. Fluctuations in sediment discharge affect a great many terrestrial and coastal processes, including ecosystem responses, because nutrients are transported with the sediment load. For example, to reproduce effectively, white perch and river herring need sandy stream beds and pond bottoms for spawning and egg survival; silt and clay deposits formed by flooding or excessive erosion can destroy these spawning beds. Stream deposits also represent huge potential sinks for, and sources of, contaminants.

Stream sediment storage and load is considered of high importance with respect to Cape Cod National Seashore's ecosystem, human impacts, and management significance. The history of the Herring River illustrates the reasons why this geoindicator is rated high across the board. Historically, the Herring River (Wellfleet, Massachusetts) was the site of a major herring run and a productive salt marsh system encompassing more than 1,100 acres. In 1909, the salt marsh system was drained to facilitate mosquito control and diked to provide additional land for development. The tidal restriction of this system has resulted in major water quality problems including hypoxia, acidic waters (pH <3), and the formation of acid sulfate soils. The conditions have caused fish kills and the lack of tidal flushing has resulted in marsh level subsidence, which in turn translates to lack of storm buffering capacity.

Cape Cod National Seashore has conducted a series of studies to evaluate options to improve habitat quality. The most beneficial approach to restoration of the system involves returning tidal flow to the area by slowly returning tidal flow to the system through the existing dike system. Previous studies have modeled the salinity changes to the system, mapped the bathymetry, and modeled the flooded area. Studies have also addressed the effects of flooding on the groundwater supply. Recently, town officials and resource managers have expressed concerns over the degree of sedimentation that might occur in the river and Wellfleet Harbor in association with restoring tidal influence to the system. The issue concerns the shellfish beds in Wellfleet Harbor and how changing the tidal regime in the river might impact sedimentation on the shellfish beds. Aquaculture (oyster and hard clam) is an important income-generating industry, and any action that is detrimental to this economy is considered an unacceptable outcome (Cape Cod National Seashore Geoscientists-in-the-Parks Proposal, 2002).

Again, the challenge for resource managers is mitigating past impacts in the National Seashore. Baseline data and research are needed, particularly for sediment-transport modeling. Seashore managers believe they are asking the right questions to produce solutions, but they don't have the answers yet. They are particularly interested in knowing how changes in sedimentation would affect tidal flats where aquaculture occurs. One study done by a NPS Geoscientist-in-the-Park in 2000 indicates that restoring the natural system of the Herring River might create additional habitat.

This geoindicator is linked to salt marshes and sea-level-rise (see relative sea level and wetlands discussions).

2.4 Soils Geoindicators

Soil Quality
Ecological Importance: Moderate
Human Impact: High (past)/Low (present)
Management Significance: Low

Soil is essential for the continued existence of life on the planet and has a major influence on terrestrial ecosystems. Soils continuously recycle plant and animal remains and are a source of plant nutrients. Soils determine the agricultural production capacity of the land and are a major support system for human life. Soils buffer and filter pollutants, store moisture and nutrients, and are important sources and sinks for CO_2, methane, and nitrous oxides. Soils also provide an archive of past climatic conditions and human influences.

Past land uses—such as farming, clear cutting, and mining of sand—modified most of the soils in Cape Cod National Seashore. With respect to past practices, human modification of soils in Cape Cod National Seashore is high, with estimates as high as 100%. The historic cultivation and burning of the land on the lower Cape, the associated current abundance of conifers, and the near shore ammonium loss through cation exchange with sea salts create acidic and nutrient poor soil conditions that contribute to stunted vegetative growth (Barnstable County Soil Survey, 1993; Brownlow, 1979; Blood et al., 1991; Valiela et al., 1997). Current resource managers in Cape Cod National Seashore are dealing with past impacts and consider present impacts to be low. Resource managers consider this geoindicator as a low priority.

"Harvard Forest" (i.e., Department of Forestry at Harvard University) has taken soil cores in conjunction with a study to classify and locate various habitat types. They consider the nutrients in the soils as a component of vegetation. Specifically the study is looking at past land use and linking these uses to current vegetation cover. Harvard Forest has also produced a soils map in conjunction with this study, which resource managers have available as "baseline" data. "Baseline" is used loosely in this context, since the baseline—prior to modification—is unknown.

Soil and Sediment Erosion
Ecological Importance: Low
Human Impact: Moderate
Management Significance: Low

Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion are essential to issues of land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems. Furthermore, soil erosion reduces the levels of the basic plant nutrients and decreases the diversity and abundance of soil organisms.

Erosion is a fundamental and complex natural process that is strongly modified (generally increased) by human activities such as land clearing, agriculture (plowing, irrigation, grazing), forestry, construction, surface mining, and urbanization.

Beach erosion is discussed under the shoreline position geoindicator, and the proliferation of social trails was discussed under the wind erosion geoindicator. Discussion of the soil and sediment erosion geoindicator focused on the upland areas of Cape Cod. In this context, soil and sediment erosion is considered of minor importance to Cape Cod's ecosystem, (i.e., rating of low); there are moderate human impacts, and the significance to park management is low. In the past, deforestation caused considerable soil erosion, and topsoil was lost because of farming practices. At present, upland soil is lost because of slope failure along the bluffs (a natural process), and social trails cause erosion along the dune fields and localized upland areas (human impacts). Such erosion is considered to be very localized and not a significant park resource issue at this time.

2.5 Hazards Geoindicators

Slope Failure (Landslides)
Ecological Importance: High
Human Impact: Low (regionally)/High (locally)
Management Significance: High

Slope failure is a natural process that can be induced, accelerated, or retarded by human actions. Slope failure may be caused by removal of lateral support through the erosive power of streams, glaciers, waves, and longshore and tidal currents; through weathering, wetting and drying, and freeze-thaw cycles in surficial materials; through land subsidence or faulting that creates new slopes; and through human actions such as cutting slopes for roads and other structures, quarrying, removal of retaining walls, and lowering of reservoirs.

In the context of Cape Cod National Seashore, the slope failure geoindicator goes hand-in-hand with the shoreline position geoindicator. Slope failure in the form of bluff retreat, maintains the National Seashore's beaches; however, it also means the loss of upland habitat. In both cases, it is of high ecological importance to the National Seashore.

On a local scale, human impacts on slope failure are high, although it is considered low regionally. In Wellfleet, at Whitecrest Beach in particular, foot traffic impacts slopes. Slope failure is of high management concern in light of public safety and preservation of cultural resources. Slope failure causes loss of roads, parking lots, lighthouses, and the frequent loss of stairways, as well as loss of human life.

As part of Cape Cod National Seashore's LIDAR monitoring, bluffs are measured; therefore, this geoindicator could be incorporated into the current monitoring program. Although the group's expertise did not include a thorough understanding of slope failure, it was suggested that work done by Bob Oldale would be beneficial if this geoindicator was developed and used by the park.

Surface Displacement

Ecological Importance:	Low
Human Impact:	Low
Management Significance:	Low

In general, most surface displacements have minor effects on landscapes and ecosystems (Berger, 1995). In the case of Cape Cod National Seashore, however, surface displacement is related to other geoindicators—relative sea level and wetlands—which have high management significance and ecosystem importance. Ditching and diking of formerly tidal wetlands has caused significant subsidence within the Seashore. The subsidence is significant not with respect to aerial extent, but to the sensitivity of habitats affected and the challenge subsidence poses to restoration efforts. Since human actions that caused the subsidence (i.e., ditching and diking) are not ongoing, surface displacement was rated low in all three categories—importance to ecosystem, human impacts, and management significance.

Another issue involving surface displacement is the locally-high decomposition of peat. There is good baseline data for this process in the Herring River and Hatches Harbor areas. John Portnoy and Evan Gwilliam are considered primary contacts for this issue.

2.6 Surficial Factors Geoindicators

Sediment Sequence and Composition
Ecological Importance: High
Human Impact: Low
Management Significance: Low

Sediment deposition is a natural process that can be strongly influenced by human activities (e.g. land clearing, agriculture, deforestation, acidification, eutrophication, and industrial pollution) within the drainage basin or sediment catchment. The chemical, physical, and biological character of aquatic sediments can provide a finely resolvable record of environmental change, in which natural events may be clearly distinguishable from human inputs.

Although sediment sequence and composition is not an active management problem and has had few human impacts in Cape Cod National Seashore, it is the foundation of the ecosystem and is, therefore, highly important because of the influence it has on other processes. There is minimal information on how the sediment sequence and composition of the National Seashore affects or records other processes. One notable exception is the extensive paleo-ecological work on lake and wetland sediments (Winkler and Sanford, 1995). The U.S. Geological Survey has taken some cores and done some modeling—particularly of estuaries. Past monitoring, although limited, revealed low contaminant levels, most of which are related to past military activities on Cape Cod; the cultivation of cranberries in the bogs; and detection of a PCB "hotspot" at Hatches Harbor.

Subsurface Temperature Regime
Ecological Importance: Unknown
Human Impact: Unknown
Management Significance: Unknown

The thermal regime of soil and bedrock exercises an important control on the soil ecosystem, on near-surface chemical reactions (e.g., involving groundwater), and on the ability of these materials to sequester or release greenhouse gases. It may affect the type, productivity, and decay of plants, the availability and retention of water; the rate of nutrient cycling; and the activities of soil microfauna.

The subsurface temperature regime reflects both the natural geothermal flux from Earth's interior and the surface temperature. The latter can be modified by human actions, such as land clearing, wetland destruction, agriculture, deforestation, flooding of land for reservoirs, or development of large settlements that give rise to "heat island" effects.

The scoping meeting participants were unable to rate the significance of this geoindicator for Cape Cod National Seashore because they did not know enough about it. Since the ecological importance is unknown, a literature search is suggested. This would provide information on whether the subsurface temperature regime warrants study and management consideration.

There was discussion pointing out the possibility of local increases in subsurface temperature because of human impacts (e.g., leaching in landfills and discharge of septic systems) and natural causes (e.g., heating up of peat because of decomposition). Later correspondence determined that decomposition of peat is not fast enough to produce detectable increases in temperature (J. Portnoy, personal communication, 4/01/02).

3.0 Recommendations

The recommendations that follow are not listed in any order of priority. If prioritizing projects becomes necessary, geoindicators that rated high for all three categories (importance to ecosystem, human impacts, and management significance) might be used as a determining factor. The recommendations that are listed are by no means all inclusive of possible geological research and monitoring. They are simply the needs that were identified during the March 11, 2002 conference call. Recommendations include research, inventory and monitoring, and public education.

A general recommendation for resource managers in Cape Cod National Seashore is to be diligent in including a geological perspective in ecosystem management, including the development of protocols, inventory and monitoring programs, decision making, and planning. There is expertise to be tapped in the Wellfleet, Massachusetts area including park staff, NOAA Sea Grant Program, the U.S. Geological Survey, as well as with the NPS Geologic Resources Division in Lakewood, Colorado.

3.1 Research Needs

3.1.1 Research on Human Impacts

Two potential research studies relating to human influences on geologic processes were identified during the scoping process:

- **Are recreational activities affecting surface water quality of ponds and shoreline position?** (Surface Water Quality Geoindicator and Shoreline Position Geoindicator)

With a permanent population of 190,000 (and rising) and a steady stream of day visitors, human traffic may be influencing shoreline change and surface water quality. Possible impacts include foot traffic by visitors accessing and recreating on beaches and extensive off-road-vehicle (ORV) use. Moreover, nearly all of the 20 kettle ponds located within Cape Cod National Seashore are used for recreation. Many of the ponds are accessible by car, making them targets for visitation. It has been observed—although not quantified—that heavy recreational use, such as swimming and fishing, at many kettle ponds has caused soil erosion on roads, trails, and shorelines, as well as sediment deposition. More data need to be gathered to quantify recreational uses and the effects on soil erosion and sediment deposition in and around ponds, which affects pond water quality, and on beaches.

- **Examine Pamet River system with respect to human influences**

An example of human influence on shoreline position was highlighted during the scoping session. Some years ago, fencing was installed at an overwash at Ballston Beach to control erosion. This fencing acts to control pedestrian traffic and promote accretion of sand. As the elevation of the overwash deposits have risen, the probability of future overwash events is believed to have decreased. The Pamet River system has been identified as a very complex and highly altered system; therefore, it is recommended that research studies be executed to better understand and quantify the human influences on the geologic processes that operate within the system. Future management actions at this site will be considered within a comprehensive management plan for the Pamet River system that takes into account the restriction to tidal influence at the north end and other historical alterations. The information from such a study would be useful for park planning and decision making.

3.1.2 Research for Baseline Data

Some basic data are needed within Cape Cod National Seashore in order to adequately manage the ecosystem and make management decisions. The topics include:

- **Mapping of offshore geology for shoreline change impacts.** (Shoreline Position Geoindicator)

Research in other locations (New York and North Carolina) suggests that erosional hotspots are related to shallow geology, which dictates sediment availability and bathymetry. There are no such data for Cape Cod National Seashore. Additional research, including mapping of the offshore geologic framework, is needed at Cape Cod National Seashore to better understand the cause or causes of erosional hotspots (R. Thieler, personal communication, 3/13/02). Until the cause or causes are understood, park management cannot anticipate the effects of hotspots on park resources through time.

3.1.3 Research for Modeling

The management of Cape Cod National Seashore has already identified the need for the following two research projects. The participants of the scoping meeting also recommend these projects.

- **Sediment transport for the Herring River.** (Stream Sediment Storage and Load Geoindicator)

In 1909, the Herring River salt marsh system was diked and drained to facilitate mosquito control and to provide additional land for development. The tidal restriction of this system has resulted in major water quality problems and marsh level subsidence, which in turn translates to lack of storm buffering capacity. Cape Cod National Seashore has conducted a series of studies to evaluate options to improve habitat quality. The most reasonable approach to restoration of the system involves returning tidal flow to the area by altering the current dike system. The question that needs investigating is how restoring the tidal regime will affect the shellfish beds in Wellfleet Harbor (Cape Cod National Seashore Geoscientists-in-the-Parks Proposal, 2002).

- **"Hotspot research."** (Shoreline Position Geoindicator)

A current study that focuses on event-scale (individual storms) is referred to as "hotspot research" and is important for understanding the shoreline position in Cape Cod National Seashore. While studying short-term impacts of storms, it was found that the shoreline erosion response was extraordinarily non-uniform, with zones of significant erosion (more than 20 m of shoreline recession) alternating with zones of virtual stability (less than 2 m of change). In periods of decreasing waves following a storm, the pattern of change nearly reversed, with the erosion zones showing strong accretion and the stable zones still exhibiting no significant change. Although the processes responsible for these erosional "hotspots" are unknown, their identification has important implications for park management (List, 2001).

3.2 Inventory and Monitoring Needs

The following recommendations were made to strengthen existing inventory and monitoring programs at Cape Cod National Seashore and suggest additional approaches for gathering needed data:

- **Continue LIDAR and SWASH monitoring of shoreline position.** (Shoreline Position Geoindicator)

As population density in Cape Cod increases, coastal erosion is becoming a critical problem. Additional information is needed to improve the fundamental understanding of storm-induced coastal erosion on a large scale (order: tens of kilometers). A combination of SWASH and LIDAR is recommended at present, although updated technologies may improve upon these survey techniques. Repeated shoreline surveys using SWASH, a recently-developed system that accurately measures shoreline position, provide quantitative data for verifying laser technology for aerial topographic surveying (LIDAR). A monitoring program that uses LIDAR and SWASH will facilitate intercomparison between methodologies for determining shoreline position.

- **Install a relative sea level monitoring station within Cape Cod National Seashore.** (Relative Sea Level Geoindicator)

If the effects of relative changes in sea level on park resources and natural processes are to be identified and quantified, relative sea level needs to be monitored within the National Seashore. The closest monitoring stations for relative sea level are in Woods Hole and Boston Harbor. The participants suggested a monitoring station in either the Provincetown or Nauset Marsh areas.

- **Expand aerial photography coverage.**

The benefits of aerial photographs for detecting changes in an ecosystem over time are undeniable. Other forms of imagery, for example from satellites, will become more feasible for monitoring in the future, as resolution improves.

LIDAR overflights cover the shoreline areas in Cape Cod National Seashore, and are conducted every two years for national parks in the northeast. There is complete aerial photography coverage of the entire park from 1991 and 2000. In such a dynamic ecosystem, which includes shorelines and uplands, it is recommended that more frequent (less than every nine years) coverage of the entire park (and areas immediate to the park boundary) be executed. Such coverage would provide additional data to use in current, informed decision making, for a variety of resources (e.g., ponds, wetlands, dunes, shorelines) within or immediately outside of the park.

- **Dune formation and sediment budget of dunes.** (Dune Formation and Reactivation Geoindicator)

Baseline information for dune formation was deemed to be lacking, although a chronology of dune movement has been established (Winkler, 1992; Madore and Leatherman, 1981; Madore and Anders, 1981). An overall assessment of the dune sediment budget is recommended to determine whether there is a need for detailed calculations on sand volume. It was suggested that LIDAR applications could be used for studies of the sediment budget of dunes in Cape Cod National Seashore.

- **Monitor social trails.** (Wind Erosion Geoindicator)

Aerial photographs revealed a "spider web" of social trails in the Herring Cove area. The Park should consider monitoring the proliferation of social trails at Herring Cove and other areas where pedestrian impacts to vegetation and associated wind erosion are a concern.

- **Incorporate the slope failure geoindicator into LIDAR monitoring of bluffs.** (Slope Failure Geoindicator)

Slope failure causes loss of roads, parking lots, lighthouses, and the frequent loss of stairways, as well as loss of human life. As part of Cape Cod National Seashore's LIDAR monitoring, bluffs are measured; therefore, this geoindicator could be incorporated into the current monitoring program. Although the group's expertise did not include a thorough understanding of slope failure, it was suggested that work done by Oldale would be beneficial if this geoindicator was developed and used by the park.

3.3 Public Education

- **Social trail proliferation.** (Wind Erosion Geoindicator)

As previously discussed, the management of Cape Cod National Seashore has identified the proliferation of social trails on dunes and beaches as a problem. Although photo points are not recommended for scientific study because they are only qualitative, it may be a useful tool for educating visitors with "before-and-after" shots.

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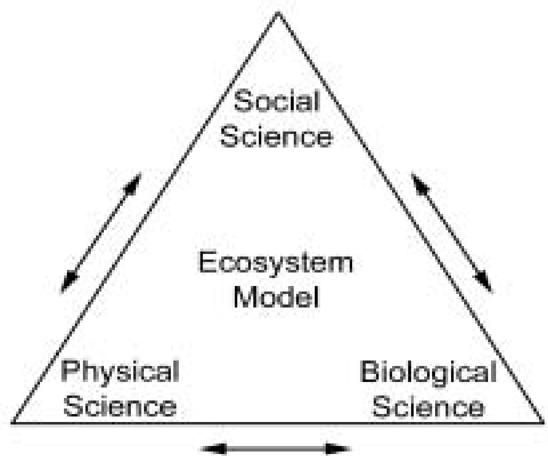
5.0 Appendices

5.1 Appendix 1

Geologic Processes - Role and Importance in Ecosystems

Ecology is a branch of biology that seeks to understand the interactions among organisms and between organisms and their physical world. Despite the importance of the physical environment to ecology, the geosciences traditionally have not been integrated into land management or ecosystem planning. This is, in part, because traditional approaches to land management perceived the landscape as a web of biological processes playing out on an inert geological stage as opposed to perceiving the landscape as a collection of processes – biological, geological, and social – that are inter-related and inter-dependent. (See Figure 1).

Figure 1. The triangular diagram illustrates conceptually how the basic sciences of ecosystem study contribute to our understanding and development of an ecosystem model.



Through the last two decades, the focus of land management has slowly been shifting from the former approach to the latter. This changing philosophy brings a need to devote increased attention to the geosciences, and especially to the interactions between the geologic and biological systems.

Geology is a major determinant of the topography, the water and soil chemistry, the fertility of soils, the stability of hillsides, and the flow styles of surface water and groundwater. These factors, in turn, determine where and when biological processes occur such as the timing of species reproduction and the distribution of habitats. Likewise, biological processes affect geological processes. For instance, biological activity contributes to soil formation and soil fertility, controls hillside erosion, traps blowing sand to form sand dunes, stabilizes drainages, and attenuates floods.

A challenge in appreciating the relevance of geology is that geologists often work with very long relative time scales; whereas, life-science specialists deal with much shorter time scales (Hughes and others, 1999). However, geologic processes occur over a variety of temporal and spatial scales. At one end of the temporal spectrum lie the processes that occur over millions of years such as the rising of a mountain range or the widening of a rift. At the other end lie the processes that occur virtually instantaneously (and often catastrophically) such as floods, landslides, and earthquakes. Between these extremes are processes that are not easily pinpointed in time but are rapid enough that we can easily observe changes in geologic features as they occur. Often, they occur continuously or in repetitive cycles. Examples of these are shoreline movement, river transport of sediment, soil formation, and cave development.

Geologic processes are as diverse spatially as they are temporally. The absorption of chemical elements to sediment particles may be the key process in determining groundwater chemistries. This process occurs at the microscopic level. In contrast, the geothermal activity at Yellowstone or Lassen Volcanic Park is related to the movement of tectonic plates at a global scale.

Geological processes that most directly impact biological processes include the following: stream and groundwater flow and their variations, erosion and deposition, weathering and mass wasting (landslides, rockfalls), earthquakes, and volcanic phenomena (eruptions, hot springs). These processes collectively operate on a variety of time scales, and the time scale of each process by itself may vary over time. It is possible for all of these processes to be operating at once in a single park. For example, an eruption in Hawaii Volcano National Park is usually accompanied by earthquakes, though minor, and can include landslides, stream diversion by lava flows, and buildup of topography when the lava flows freeze. These processes destroy some habitats while creating others, and introduce new substrates for early successional stages, thus maintaining habitats for early successional species. In other words, even on human time scales, the geological substrate for ecosystems is as dynamic and constantly changing as are the ecosystems themselves. In fact, one cannot understand ecosystem dynamics without also understanding the dynamics of their substrate. This type of human-scale geologic process also can impact the visitors to the parks by presenting potential hazards. (Parrish and Turner, 2000)

Even what is viewed as a static geologic resource contributes to ecosystem mosaics and biodiversity. For example, in Grand Canyon National Park, the nesting sites of the spotted owl are restricted to ledges formed in a specific rock layer in the park, the Hermit Shale. Thus, management of the nesting sites of this threatened species requires knowledge of the geologic substrate. Understanding why this rock layer is so important to the owls indicates the need for integrated biogeological research. An example of floral dependence on geology is the Winkler's cactus, which grows only on the white, powdery soil and pebbles eroded from part of the Morrison Formation in Canyonlands National Park. In this case, not only is the distribution of the rock layer itself important to the plant, but the erosion products themselves are quite fragile, requiring management of both the plant and its delicate habitat. (Parrish and Turner, 2000 personal communication)

The geologic resources of a park – the soils, the caves, the fossils, the stream network, the springs, the volcanoes, etc. – provide the precise set of physical conditions required to sustain the biological system. Interference with geologic processes and alteration of geologic features inevitably affect habitat conditions. For example, the channelization of the Virgin River in Zion National Park caused the channel to incise, lowering the groundwater table and reducing the habitat of floodplain obligate species (Steen, 1999). In Jean Lafitte National Historic Park and Preserve, externally triggered land subsidence is raising the water level in the park inundating the swamp forest and reducing habitat for forest-dependent species (Sauier, 1994). Alternatively, a manipulation of the biological system can trigger changes in the geologic system that can re-affect the biological system. For example, when beavers are trapped to increase the density of hydrophobic shrub species, the river morphology and sediment transport capacity changes resulting in a redistribution of the types of fish species that dominate.

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5.2 Appendix 2

Human Influences on Geologic Processes in and Adjacent to National Park Units

The term "human influences" is the central theme for the second part of this GPRA goal. The term has purposefully been selected in order to explore the full breath of possibilities, both inside the park and external to the park boundaries. Adjacent land use, consumptive activities, administrative practices as well as public visitation can all influence earth surface processes. An effective way to illustrate human influences on the processes is to go through some examples. This is not a comprehensive treatment and these examples do not occur in or adjacent to all parks.

Land Uses (most commonly occurring adjacent to parks)

- Agriculture – intense use can cause loss of soil, erosion, and dust storms. Use of pesticides can affect both surface and groundwater quality.
- Grazing – overgrazing can cause loss of vegetation, soil erosion and create conditions conducive to fires and the spread of non-native species.
- Forestry – intensive logging or clear cutting creates conditions for increased hillslope and fluvial erosion; sediment carried away can cause increased sediment loading in streams that can effect aquatic habitat.
- Water impoundment – This has the potential to affect one segment of a stream or river or the entire watershed. Controlled volume of flow does not duplicate natural events such as floods and drought. It can affect the water temperature, sediment load, and change the stream morphology and habitat that are dependent on such things as flushing flows within a fluvial system.
- Urbanization – This can cause a host of influences, but a few stand outs are; change in drainage patterns, increased runoff and erosion, effects on surface and groundwater quality and quantity, release of toxins into the air and water, and increased humidity in arid regions.
- Dredging, beach mining, river modification, installation of protective structures, removal of back-shore vegetation, and alterations of the near-shore can potentially alter shoreline processes, position and morphology by changing the sediment supply.

Consumptive Uses

- Groundwater withdrawal – In instances where the groundwater resource is depleted to the point where recharge cannot keep pace with withdrawals, the groundwater-dependent ecosystem is effected. Where withdrawal has been intense for a number of decades, the surface has been known to collapse (subside) over huge areas by as much as 10 feet.
- Oil and gas production – this can cause surface subsidence and contamination of water aquifers and cave and karst systems.
- Mining (open pit and underground) – This can reconfigure the landscape over large areas bringing significant and permanent change to the landscape. It can affect the surface and groundwater by releasing heavy metals or other chemicals into the system, as well as affecting the groundwater level.
- Mineral & Materials Mining – the quarrying of stone, mining of gravel and borrowing of soil, if done in large volume or smaller volume but in critical locations in the ecosystem, impacts

geologic process by the shear volume of material removed and pumping to keep the operation dry can lower the water table.

Administrative Uses

- Roads and bridges – Often these have been constructed with little or no consideration for natural processes. Roads can disrupt drainage, cause erosion and create hillslope instability. The abutments for bridges can change the flow and morphology of streams and rivers.
- Parking lots – Large paved areas inhibit infiltration and increase runoff. Water flowing from parking lots can cause erosion and gullying. Runoff pollution effects surface and groundwater.
- Facilities placed over caves – Contaminants from restrooms and other water usage, plus runoff can reach caves and karst systems below causing damage to the fragile subterranean ecosystems.
- Water consumption – In arid and semi-arid environments, water is a scarce and critical resource. Withdrawal of water may have significant impacts on the ecosystems, such as riparian zones.
- Trails – If they are poorly located with respect to soil, rock and vegetation considerations, they have the potential to exacerbate erosion, rock falls and slope instability.
- Armoring streams, rivers and coast – Rock armoring changes the fluvial and shoreline processes thereby affecting the ecosystem by causing such things as increased erosion or deposition down stream of the riprap.
- Planting exotic species – Planting or not controlling non-native species can have a significant effect on erosion and sedimentation processes.

Visitor Use

- Trampling, compaction of soil – Over use by too many people in a small area can compact the soil and can reduce soil productivity and increase erosion.
- Social trails – Depending on the nature of the environment, development of unplanned trails can seriously damage fragile resources (such as in caves, wetlands, microbiotic crust, cinder cones, tundra, etc.)
- Touching fragile features – A number of geologic features have taken years to form through geologic processes, and although seemingly rock-hard, they can be rather fragile. Examples include stalactites and stalagmites in caves. Also included are erosional features, such as arches, bridges, hoodoos, and badlands. Crystals are another example. Visitors touching or climbing on all these features can cause irreparable damage.
- Power boating – Over a period of time, wakes from small and large boats alike can contribute to shoreline erosion. Fuel contamination can affect water quality.

These examples are provided to stimulate the readers thinking, raise awareness and perhaps contemplate additional cases from one's own experience.

5.3 Appendix 3

Geoindicators – A Tool for Assessment

Geoindicators are measures (magnitudes, frequencies, rates, and trends) of geological processes and phenomena occurring at or near the Earth's surface and subject to changes that are significant in understanding environmental change over periods of 100 years or less (Berger and Iams 1995). They measure both catastrophic events and those that are more gradual, but evident within a human life span. Geoindicators are not geologic processes. However, there is a strong correlation between the two. Geoindicators can be used to monitor and assess changes in fluvial, coastal, desert, mountain and other terrestrial areas. They can also be used through paleoenvironmental research to unravel trends over the past few centuries and longer, thus providing important baselines against which human-induced and natural stresses can be better understood.

Geoindicators describe processes and environmental parameters that are capable of changing without human interference, though human activities can accelerate, slow or divert natural changes (e.g. Goudie 1990, Turner et al. 1990). Humans are certainly an integral part of nature and the environment, but it is essential to recognize that nature and the environment are ever changing at one temporal and spatial scale or another, whether or not people are present. Environmental sustainability must, therefore, be assessed against a potentially moving background. Table 1 is a checklist of 27 geoindicators developed by the International Union of Geologic Sciences through its Commission on Geologic Sciences for Environmental Planning.

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Table 1. Geoindicators: natural vs. human influences, and utility for reconstructing past environments.

Geoindicator	Natural Influence	Human Influence	Paleo Reconstruction
Coral chemistry and growth patterns	H	H	H
Desert surface crusts and fissures	H	M	L
Dune formation and reactivation	H	M	M
Dust storm magnitude, duration and frequency	H	M	M
Frozen ground activity	H	M	H
Glacier fluctuations	H	L	H
Groundwater quality	M	H	L
Groundwater chemistry in the unsaturated zone	H	H	H
Groundwater level	M	H	L
Karst activity	H	M	H
Lake levels and salinity	H	H	M
Relative sea level	H	M	H
Sediment sequence and composition	H	H	H
Seismicity	H	M	L
Shoreline position	H	H	H
Slope failure (landslides)	H	H	M
Soil and sediment erosion	H	H	M
Soil quality	M	H	H
Streamflow	H	H	L
Stream channel morphology	H	H	L
Stream sediment storage and load	H	H	M
Subsurface temperature regime	H	M	H
Surface displacement	H	M	M
Surface water quality	H	H	L
Volcanic unrest	H	L	H
Wetlands extent, structure, and hydrology	H	H	H
Wind erosion	H	M	M

H – HIGHLY influenced by, or with important utility for
M – MODERATELY influenced by, or has some utility for
L – LOW or no substantial influence on, or utility for

Note: This table illustrates in a general way the relative roles of natural and human-induced changes, both direct and indirect, in modifying the landscape and its geological systems. However, it excludes from consideration influences that may be brought about by anthropogenically-induced climate change.

5.4 Appendix 4

Description of Geologic Processes

<u>Difference between Geologic Processes and Geoindicators:</u>
Geoindicators are parameters that can be used to assess changes in rates, frequencies, trends, and/or magnitudes in geological processes. See the examples below:

Glaciation is the process by which ice accumulates, flows, and recedes, shaping the land surface over which it moves. Glacier fluctuations, in the geoindicator sense, are changes in ice mass balance and position that are important to track in understanding and forecasting changes to "cryospheric" mountain ecosystems and the river systems that flow from them.

Volcanism is the process whereby magma reaches the surface and erupts to shape the surrounding landscape (and distant landscape through ash and dust falls). Volcanic unrest is the geoindicator that takes into account all the various kinds of changes (geophysical, geochemical and neo-tectonic) that occur prior to an eruption.

Dynamic coastal processes cause changes in sea level, coastal erosion and deposition, wave patterns, and climate. Shoreline position is the geoindicator that helps to assess the cumulative effect of these processes. Relative sea level is a simple measure that relates coastal subsidence and uplift, and changes in the sea-surface elevation that may be due to de-glaciation, thermal expansion (climate warming), or neo-tectonics.

<u>Geologic Processes</u>
The geologic processes operating on the landscape may be divided into two types, exogenetic and endogenetic. Exogenetic processes are those that operate at or near the earth's surface. These processes have a number of agents like wind, water, and ice that cause erosion and deposition and include very basic processes such as mass wasting and physical & chemical weathering. Endogenetic processes are generated within the earth's crust and mantle and include volcanism and tectonism (Toy and Hadley, 1987). These processes shape the configuration of the earth's surface (Easterbrook, 1969).

<u>Fluvial Erosion and Deposition</u>
The precipitation that falls on the earth either runs off the surface, soaks into the ground, or evaporates back into the atmosphere. That portion which runs off the surface of the land eventually collects into rivulets, gullies and streams which continuously erodes the land and deposits material elsewhere. Landscapes sculptured by fluvial erosion and deposition bear characteristic features that differ from those developed by other processes. Oxbows, point bars, alluvial fans, and deltas are but a few examples.

<u>Glacial Erosion and Deposition</u>
Glacial processes also produce unique landforms, such as kames, eskers, drumlins, various kinds of moraines, rouches moutonnees, and many others. Glaciers move more slowly downslope than do streams, but are nevertheless capable of carrying large quantities of material derived by erosion from valley sides and bottoms. Glaciers produce the classic "U" shaped valleys of glaciated areas, as well as horns, aretes, and cirques. Frozen ground features include such things as pingos, patterned ground, and solifluction ridges.

Groundwater Solution and Deposition
Some of the precipitation that falls from the atmosphere seeps into the ground, where it is stored until it emerges along valley sides and floors, lakes, bays and oceans. While in contact with rock material, groundwater promotes solution and other types of chemical weathering. Transport of weathered and dissolved material leads to development of unique landforms (caves and karst), especially in areas of soluble rocks, such as limestone. Heating of groundwater may result in hot springs, geysers, paint pots, and frying pans, as well as produce siliceous sinter deposits and promote diatom activity.

Mass Wasting
Mass wasting is the downslope movement of soil and rock material under the influence of gravity without the direct aid of other agents, such as water, wind, or ice. Water and ice, however, are frequently involved in mass wasting by reducing the strength of rock and soil and by contributing to plastic and fluid behavior of soils. Mass wasting is capable of transporting large quantities of material from hill slopes to valley floors. Mass wasting can be rapid, for example a rock fall or landslide, or slow as in soil creep.

Lacustrine and Oceanic Processes
Shorelines of oceans, seas and large lakes are modified continuously by the abrasive action of waves beating against the shore and deposition of material by wave and current action. Terraces, spits, bars, turbidity deposits and other features result from these processes.

Eolian Processes
Wind is a less vigorous agent of erosion, transport, and deposition of material than water, but in arid and semiarid regions, or areas having an abundant supply of unconsolidated sand, wind is locally an important agent producing yardang, ventifacts, lag deposits, loess deposits, and dunes. Sand dunes are the main attraction in park units such as Great Sand Dunes National Monument, Colorado, and White Sands National Monument, New Mexico.

Weathering
Mechanical disintegration and chemical decomposition of rocks cause them to be broken down into smaller pieces. In those areas where rocks offer differing resistance to weathering, differential weathering etches out weaker rock zones producing bizarre honeycomb patterns, and coupled with other agents of erosion can cause valleys to develop. In areas where mechanical weathering is dominant, the topography develops angular hill slopes, whereas in areas dominated by chemical weathering, smooth, rounded slopes are developed.

Volcanism
Eruption of lava on the surface produces very distinctive landforms, which if not too old, are easily recognized, such as at Craters of the Moon National Monument, Idaho, Lava Beds National Monument, California, and El Malpais National Monument, New Mexico. These include such features as shield volcanoes, strato or composite volcanoes, cinder cones, various kinds of lava flows, tumuli, hornitos, pressure ridges, spatter cones and ramparts, lahar deposits and many more.

Tectonism

Deformation of the earth's crust caused by tension, shear, and compression may produce initial small scale landforms like fault scarps and sag ponds or produce huge regional scale folding or thrusting that only become exhumed by erosion later. Among common topographic features produced initially by tectonic movement are scarps, horsts, and grabens. Fault gouge is more easily eroded than unfractured rock, which can hasten the process of erosion. Relief of pressure from faulting can result in decompression melting, dike emplacement, and even volcanic eruption. Tectonism is a process that frequently is working in concert with other processes.

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